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Stability analysis for yield and yield component traits of winged bean

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ABSTRACT

Winged bean is an underutilized nutrient-rich legume that offers great importance in food security under climate change. Despite its importance, stable high-yielding varieties across a wide range of environments are unavailable for commercial cultivation. A study involving a proper understanding of genotypes and Genotype × Environment interactions (GEI) on yield and yield component traits to identify best-performing stable genotypes across different environments is crucial. Eleven genotypes of winged bean were characterized and evaluated in two locations for two years (2020 & 2021) following a randomized block design with three replications. Characterization of genotypes showed varying leaf shape, leaflet size, pod surface, pod shape, seed colour, and seed shape. The genotype 'MZWB-L2' performed significantly better than all the checks in the study with exceptionally longer green pod length 47.97 cm, 3.60 cm green pod width, 110.76 g green pod weight, 55.67 no. of pods/plant, 19.04 no. of seeds/pod, 6.25 kg green pod yield/plant and 391.20 g seed yield/plant. Highly significant differences were observed due to genotypes, environments, and GEI. Based on the AMMI model, the first and second component explained more than 92% of the interaction variation. The genotype 'MZWB-L2' exhibited maximum trait value in different environments with specific adaptability. Moreover, this genotype is found suitable for commercial cultivation under specific environments and as a suitable parent for crop improvement. The two genotypes 'MZWB-L1' and 'RWBGP-96' are less affected by GEI, exhibiting general stability and performing satisfactorily for yield and yield component traits. Thus, genotypes MZWB-L2, MZWB-L1 and RWBGP-96 are considered suitable for cultivation in the Northeastern hill region of India.

1. Introduction

Winged bean [*Psophocarpus tetragonolobus* (L.) DC.] is an underutilized potential crop belonging to the family *Fabaceae*. It is known by many names such as Manila bean, Goa bean, princess pea, four-angled bean, asparagus pea, and Bepuithlanei or Bepuipawr in Mizo. It is a self-pollinated tropical legume crop grown as an annual crop which has nearly all of its parts, like the tender pods, immature and mature seeds, tender leaves, and tuberous roots, edible and fit for consumption and thus was nicknamed 'One Stop Supermarket' (Soni *et al.*, 2022a), 'Supermarket on a Stalk' and 'One Species Supermarket' (National Academy of Sciences, 1975). It is believed to have originated from South-eastern Asia or Papua New Guinea (Bassal *et al.*, 2020). It thrives well in the hot and humid climates and is distributed widely in the Southern and North-eastern regions of India. In Mizoram, winged bean is grown sporadically in *jhum* lands as the sole crop and mixed farming. It is generally consumed as a raw vegetable, soup, curry, chutney, and salad. This crop is abundant in natural antioxidants (Maimako *et al.*, 2022), polyphenols and flavonoids (Kim *et al.*, 2003; Bassal *et al.*, 2020). The seeds have shown promising blood-pressure

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lowering properties (Chay *et al.*, 2018) and tuberous roots are highly protein-rich (Kortt and Caldwell, 1984) and hence can be used as a substitute for protein supplements (Soni *et al.*, 2022b). Additionally, substantial nodulation plays an important role for increasing soil fertility (Lepcha *et al.*, 2017). As winged bean has excellent nutritional content and can flourish luxuriantly even in unfavourable climatic conditions, it has become an important crop for food security under climate change.

A wide variability of winged bean genotypes exists in Mizoram. The local germplasm are a repository for gene variants, and if it is not conserved, genetic diversity will be endangered. Genetic resource management of vegetable crops should focus not only on commercialized popular crop species but also on neglected, underutilized vegetables that receive little to no attention. Lack of scientific interventions on this crop has resulted in lower production in Mizoram. Screening of landraces to identify high-yielding superior genotypes may lead to adopting winged bean cultivation on a commercial scale. As yield relies on many other contributing traits, it is highly influenced by the environment, so the interaction of genetic and non-genetic factors on trait expression is critical. Given the lack of information on the winged bean, it is crucial to comprehend the response of genotype to environmental changes so that varietal suggestions can be made. Assessment of winged bean performance at different environments to study the Genotype × Environment Interactions (GEI) would give information about yield potentials and their stability across environments. This will help to identify the best genotypes adapted to specific locations and across different locations/environments to enhance the yield of winged beans and improve their production.

Specific tools are present to predict the performance of a genotype in different environments. In breeding programmes, the Additive Main Effects and Multiplicative Interaction (AMMI) analysis is widely used to effectively estimate and interpret multi environment data structure (Ebdon and Gauch, 2002; Samonte *et al.*, 2005). Many researchers have used the AMMI biplot analysis to identify best performing stable genotypes in many crop species (Bhartiya *et al.*, 2017; Tiwari and Rastogi, 2020; Greveniotis *et al.*, 2022; Tiwari *et al.*, 2022). The AMMI based stability parameter, such as AMMI Stability Value (ASV) as per Purchase *et al.* (2000) is one of the most appropriate single methods to rank genotypes through the AMMI model and describe the stability of genotypes. A significant correlation of stability measures between ASV and Shukla and Wricke (Wi), and Eberhart and Russel (S2d) were observed during the analysis of cultivars stability while Linn and Binns (Pi) and Finlay and Wilkinson (b) showed limited correspondence with any of the other methods (Eberhart and Russell, 1966; Finlay and Wilkinson, 1963). It is one of the most useful measures for genotype stability. Extensive collection, characterization, and evaluation of germplasm and identification of superior genotypes with high stability across environments/locations that can be used for commercial cultivation and as a potential parent for winged bean improvement is crucial. As a result, the current work was carried out to investigate the pattern of GEI in eleven-winged bean genotypes to select high-yielding and stable genotypes for North-eastern hill region of India.

2. Materials and methods

A total of eleven genotypes (Table 1), including AKWB-1, RMDWB-1 (national checks, NC) and MZWB-L1(local check, LC) were evaluated at ICAR experimental fields in two locations *i.e.*, Kolasib (Mizoram) and Umiam (Meghalaya) for two consecutive years (Table 1). The experiment was conducted in randomised block design with three replications during the *Kharif* of 2020 and 2021.

Table 1. Sources of winged bean genotypes and a brief description of experimental locations

Genotypes	Sources of genotypes
MZWB-L2	Thingdawl, Kolasib, Mizoram
RWB-37	BAU, Ranchi, Jharkhand
RWB-38	BAU, Ranchi, Jharkhand
RWB-39	BAU, Ranchi, Jharkhand
RWBGP-95	IGKV, Ambikapur, Chhattisgarh
RWBGP-96	IGKV, Ambikapur, Chhattisgarh
RWBGP-97	IGKV, Ambikapur, Chhattisgarh
IWB-1	IGKV, Ambikapur, Chhattisgarh
MZWB-L1 (LC)	Aizawl, Mizoram

AKWB-1 (NC)	MPKV, Rahuri, Maharashtra					
RMDWB-1 (NC)	IGKV, Ambikapur, Chhattisgarh					
Experimental locations						
States	Soil type	Years	Legend	Global position		Altitude (m)
Kolasib, Mizoram	Sandy loam	2020	2020-MZM	24°12’46”N	92°40’28”E	617.49
		2021	2021-MZM			
Umiam, Meghalaya	Sandy loam	2020	2020-BPN	25°4’36”N	91°55’37”E	945.71
		2021	2021-BPN			

The winged bean genotypes were grown as a sole crop on a raised bed of size 4 m × 4 m × 0.15 m, at a spacing of 70 cm × 45 cm, accommodating 50 plants/plot. Standard cultivation practices for winged bean were followed as per Soni *et al.* (2022b). The characterization was done as per the revised descriptor of IBPGR (1982). Observations were recorded from five random plants from each plot like green pod length-GPL (cm), green pod width-GPW (cm), green pod weight-GPWG (g), no. of pods/plant (NPPP), no. of seeds/pod (NSPP), 100 seed weight-HSW (g), green pod yield/plant-PODYPP (kg) and seed yield/plant-SYPP (g). The tender green pods are taken for data recording at edible maturity stage for vegetable purpose. Five uniform pods were selected from each plot for measuring the length and width of the pods using a measuring scale and Vernier calliper, respectively. The weight of a pod was averaged from these five pods and no. of seeds/pod was counted. The no. of pods/plant was also counted from five uniform plants from each plot. The seeds are carefully harvested by collecting the dry pods from the plant before seed shattering. The dry pods are brown, and when shook, the loosened seeds inside the pod make a rattling sound. After shelling, the seeds were weighed using electronic weighing balance for seed yield/plot (g). Healthy seeds were counted by hand to record 100 seed weight (g). The AMMI based statistics was performed in R software 4.0.3 (R Core Team, 2020) using ‘metan’ package (Olivoto and Lucio, 2020).

3. Results and discussion

The genotypes varied in leaf shape (ovate-lanceolate to deltoid), leaflet size (small, moderate to large), corolla colour of wings and standard (light blue to blue or blue with purplish tint wings), pod colour (green), pod surface (medium rough to rough), pod shape (semi-flat to rectangular), seed colour (cream, tan or brown), seed shape (oval, round or slightly square), seed surface (smooth) and hilum colour (Black to brown) (Table 2). A comprehensive characterization lays the groundwork for effective germplasm conservation and future genetic enhancement (Fitriana and Susandarini, 2019).

In this study, the performance of 11 winged bean genotypes with respect to yield and yield component traits *viz.*, green pod length (cm), green pod width (cm), green pod weight (g), no. of pods/plant, no. of seeds/pod, 100 seed weight (g), green pod yield/plant (kg) and seed yield/plant (g) in two locations for two years (2020 and 2021) were pooled and presented in Table 3. Genotype, MZWB-L2 (47.97 cm) has exhibited green pod length greater than 71.1% from the local check, 178.9-204.5% from the national check, and 130.8% from its grand mean (Figure 1).

Table 2. Qualitative characterization of eleven-winged bean germplasm

Characters	**MZWB-L2**	**RWB-37**	**RWB-38**	**RWB-39**	**RWBGP-95**	**RWBGP-96**	**RWBGP-97**	**IWB-1**	**MZWB-L1**	**AKWB-1**	**RMDWB-1**
Leaf shape	Ovate lanceolate	Deltoid	Deltoid	Deltoid	Deltoid	Deltoid	Deltoid	Deltoid	Deltoid	Deltoid	Deltoid
Leaflet size	Large	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Small	Moderate	Moderate
Corolla colour of wings and standard	Light Blue	Other (Blue with purplish stripe wings)	Blue	Blue	Blue	Blue	Blue	Blue	Other (Blue with purplish tint wings)	Blue	Blue
Pod colour	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
Pod surface texture	Rough	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Pod shape	Semi- flat	Rectangular	Rectangular	Rectangular	Rectangular	Rectangular	Rectangular	Rectangular	Rectangular	Rectangular	Rectangular
Seed colour	Cream	Tan	Cream	Tan	Brown	Cream	Tan	Tan	Tan	Tan	Tan
Seed shape	Oval	Round	Round	Round	Round	Round	Other (slightly squared)	Round	Round	Round	Round
Seed surface	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth
Hilum colour	Black	Black	Other (Brown)	Black	Black	Other (Brown)	Black	Other (Brown)	Other (Brown)	Other (Brown)	Other (Brown)

Figure 1. Variation of pod length from different genotypes under study

Four genotypes exhibited greater values for green pod width (cm) than the grand mean. Maximum green pod width (cm) was recorded in RMDWB-1 (3.63 cm), which is significantly on par with MZWB-L2 (3.60 cm), followed by RWB-37 (3.17 cm) and RWBGP-97 (3.17 cm). Based on the green pod weight. MZWB-L2 (110.76 g) exhibited significantly highest green pod weight as compared to all the checks, AKWB-1 (18.42 g), RMDWB-1 (25.08 g) and MZWB-L1 (16.60 g) which exhibited values below grand mean. Five genotypes have exceeded the grand mean for no. of pods/plant with the significantly highest record in MZWB-L2 (55.67) as compared to AKWB-1 (19.17), RMDWB-1 (24.33) and MZWB-L1 (33.00). The significantly highest no. of seeds/pod was recorded in MZWB-L2 (19.04) as compared to AKWB-1 (10.75), RMDWB-1 (12.74) and MZWB-L1 (9.25). Five genotypes have exceeded the grand mean for 100 seed weight (g) with significantly highest in RWBGP-97 (92.00 g), followed by RWBGP-96 (55.72 g), while the checks have recorded AKWB-1 (40.17 g), RMDWB-1 (51.05 g) and MZWB-L1 (46.47 g). None of the test genotypes except MZWB-L2 (6.25 kg) exceeded grand mean for green pod yield/plant (kg) which is significantly more than AKWB-1 (0.36 kg), RMDWB-1 (0.60 kg) and MZWB-L1 (0.55 kg). Six genotypes exceeded the grand mean for seed yield/pod (g) in which the significantly highest production is recorded in MZWB-L2 (391.20 g) as compared to AKWB-1 (85.26 g), RMDWB-1 (156.30 g) and MZWB-L1 (141.80 g). The genotype 'MZWB-L2' performed significantly better in yield and yield component traits under different environments when compared to the local and national checks.

Table 3. Mean values of yield and yield component traits across different locations for two consecutive years (2020 & 2021).

Genotypes	Green pod length (cm)	Green pod width (cm)	Green pod weight (g)	No. of pods/plant	No. of seeds/ pod	100 seed weight (g)	Pod yield/plant (kg)	Seed yield/plant (g)
MZWB-L2	47.97	3.60	110.76	55.67	19.04	36.25	6.25	391.20
RWB-37	18.37	3.17	36.06	14.33	11.67	44.15	0.51	72.99
RWB-38	16.83	2.73	24.33	9.67	11.00	34.79	0.24	37.10
RWB-39	16.69	3.01	24.00	26.00	12.67	53.58	0.64	185.32
RWBGP-95	17.63	2.93	27.00	16.33	9.00	45.92	0.45	68.23
RWBGP-96	18.23	3.00	25.67	19.33	12.92	55.72	0.50	139.51
RWBGP-97	15.90	3.17	31.62	8.22	7.00	92.00	0.27	55.15
IWB-1	16.00	2.88	21.64	24.34	11.69	50.87	0.54	150.93
MZWB-L1	28.03	2.77	16.60	33.00	9.25	46.47	0.55	141.80

(LC)								
AKWB-1 (NC)	15.75	2.75	18.42	19.17	10.75	40.17	0.36	85.26
RMDWB-1 (NC)	17.20	3.63	25.08	24.33	12.74	51.05	0.60	156.30
Grand mean	20.78	3.06	32.84	22.76	11.61	50.09	0.99	134.89
CD (p=0.05)	1.25	0.13	2.24	1.12	0.64	3.59	0.16	21.79

The key to selecting and recommending cultivars, and choosing appropriate production and test environments, is GEI analysis (Manrique and Hermann, 2000). The yield and quality of a crop is highly influenced by environmental changes, so understanding the GEI is essential. GEI study is a critical part in variety evaluation for the release of stable high-yielding genotypes (Sood *et al*., 2020). The AMMI analysis uses analysis of variance (ANOVA) to analyze the additive part (main effect) followed by analyzing the non-additive part through Principal Component Analysis (PCA) applied to the sums of squares allocated by the ANOVA to the GEI to identify suitable genotypes with both high stability and high mean performance across environments (Sabaghpour *et al*., 2012; Gauch,1993). The AMMI variance analysis for yield and yield component traits showed that green pod length (cm) and 100 seed weight (g) are highly significant for environment, genotypes and GEI while pod yield/plant (kg) and seed yield/plant (g) showed significant variances due to genotypes and GEI (Table 4).

The G × E component was further divided and explained by three IPCA (interaction principal components axes), *viz.* IPCA1, IPCA2 and IPCA3. The IPCA1 and IPCA2 explained 93.8% (IPCA1: 81.8% and IPCA2: 12.0%), 92.6% (IPCA1: 74.5% and IPCA2: 18.1%), 97.0% (IPCA1: 62.6% and IPCA2: 34.4%) and 96.6% (IPCA1: 86.2% and IPCA2: 10.4%) of total variation for green pod length, 100 seed weight, green pod yield/plant and seed yield, respectively. This is concurrent with the reports of Darai *et al.* (2017), Simion *et al.* (2018), Manivannan *et al.* (2020), Tiwari *et al.* (2022) and Anuradha *et al.* (2022) in which the GEI was partitioned into more than two IPCAs by the AMMI model. The mean sum of squares due to genotypes is the largest, indicating greater variation exists as a result of genotypes in the expression of the traits. Several workers have carried out the combined analysis of variance (Gajghate *et al*., 2021; Lal *et al*., 2021), which suggested the effect of genotypes as a predominant source of variation followed by GEI and environmental effect.

Table 4. Additive Main effects and Multiplicative Interaction (AMMI) analysis of variance for yield and its components across environments

Source of variation	Df	Green pod length (cm)			100 Seed weight (g)			Pod yield/plant (kg)			Seed yield/plant (g)		
		MSS	Pr(>F)	Proportion	MSS	Pr(>F)	Proportion	MSS	Pr(>F)	Proportion	MSS	Pr(>F)	Proportion
Environment	3	13.011	0.000 **	-	28.243	0.001 **	-	0.03	0.134	-	435.495	0.365	-
Replications in Environment	8	0.278	0.929	-	1.811	0.963	-	0.012	0.444	-	358.459	0.159	-
Genotypes	10	1127.806	0.000 **	-	2989.406	0.000 **	-	36.735	0.000 **	-	114829.939	0.000 **	-
G × E	30	12.229	0.000 **	-	39.488	0.000 **	-	0.052	0.000 **	-	2328.28	0.000 **	-
IPCA1	12	25.021	0.000	81.8	73.552	0.000	74.5	0.081	0.000	62.6	5017.31	0.000	86.2
IPCA2	10	4.384	0.000	12.0	21.452	0.001	18.1	0.053	0.000	34.4	725.447	0.002	10.4
IPCA3	8	2.848	0.001	6.2	10.939	0.085	7.4	0.006	0.874	3	298.277	0.266	3.4

Residuals	80	0.735	-	-	6.006	-	-	0.012	-	-	233.691	-	-
Total	161	75.229	-	-	203.994	-	-	2.308	-	-	8142.022	-	-

*significance at p≤0.05 **significance at p ≤ 0.01

The AMMI biplots are an effective analytical tool for determining the influence of main effects and interaction effects on yield and yield component traits. In AMMI1 biplot, the main effects (genotype mean and environment mean) are plotted against IPCA1 scores for both genotypes and environments. The second biplot, on the other hand, is AMMI2, which plots IPCA1 and IPCA2 scores. In the AMMI1 biplot, the usual interpretation of biplot is that the displacements along the abscissa indicate differences in main (additive) effects, whereas displacements along the ordinate indicate differences in interaction effects. Genotypes that cluster together have similar adaptability, whereas environments that cluster together affect genotypes in the same way (Kempton, 1984). From the graphical analysis of IPCA1 with pod length, it is revealed that MZWB-L2 has the highest value for pod length and positive AMMI1 score (Figure 2). In AMMI model, if genotype is having high value for trait which is greater than grand mean value and near to zero IPCA score are considered under general adaptability across environments. However, genotypes with high value for trait and IPCA scores towards larger value are considered under specific adaptability to the environments. So, the genotype MZWB-L2 is considered under specific adaptation due to high green pod length and large IPCA score. The genotype MZWB-L1 is found stable across the environment for green pod length as its lies closer to the centre point in the biplot. Genotypes RWBGP-97, IWB-1 and IWB-2 are less affected by GEI for 100 seed weight as they are on the right side of the perpendicular. Out of these genotypes, IWB-1 is found to have general adaptability due to high value for trait than grand mean and stable for 100 seed weight across environments. MZWB-L2 has the maximum value for green pod yield/plant and positive AMMI1 score, it may be considered under specific adaptability to the environment. No genotypes were found to have high value for green pod yield/plant than the grand mean for general adaptability. For seed yield/plant, MZWB-L2 and RWB-39 are less affected by GEI as they are on the right side of the perpendicular. From these, the genotype MZWB-L2 is having general adaptability due to high value for seed yield/plant than the grand mean and near to zero IPCA score.

The AMMI2 biplot is a plot of IPCA1 *vs.* IPCA2, which explains the degree to which a genotype interacts with the environment. The environmental scores are joined to the origin by side lines. Short arrow locations do not have strong interaction forces, while those with long arrows exert strong interaction. The genotypes further away from the ordinate showed more selective adaptation to the environment, while those closer to the ordinate expressed general adaptation (Ebdon and Gauch, 2002; Gauch *et al.*, 1996). Genotypes that cluster closely together on the plot will produce similar yields across all years, whereas genotypes that have drifted apart produce a range of yields or exhibit a varied pattern of environmental response. When environments and genotypes belong to the same sector, they interact favourably; when they belong to opposite sectors, they interact unfavourably (Osiru *et al.*, 2009). Genotypes MZWB-L1, RWB-38 and IWB-1 are stable for green pod length as they are closer to origin and showed lesser interactive forces with the environment. On the other hand, MZWB-L2, RWBGP-97, and RWB-37 showed a difference in green pod length across the environments. These genotypes are away from the origin, indicating more interaction with the environment for green pod length. Genotypes MZWB-L1, MZWB-L2, RWBGP-95 and RWBGP-96 are closer to one another and near the origin, thus are considered stable for 100 seed weight. While RWB-39, RWBGP-97, and AKWB-1 were scattered far away from the centre, thus rendering them less stable. For green pod yield/plant, RWB-37, RWBGP-96, and RMDWB-1 are considered stable, while MZWB-L2, IWB-1, and RWB-39 were identified as the most unstable genotypes with high response to the environment for green pod yield/plant. RWBGP-95, RWB-37, RWB-38 and MZWB-L1 are at the proximity of the origin and thus are considered stable across environments for seed yield/plant, while MZWB-L2, IWB-1, and RWB-39 are found unstable across environments for seed yield/plant (Figure 2, 3, 4 & 5).

According to IPCA1 and IPCA2 scores of genotypes and environment, a genotype is found to be specifically suited to an environment if it is close to that environment (Shafii *et al.*, 1992; Kumar *et al.*, 2016). Thus, genotypes AKWB-1 and RMDWB-1 were identified as superior for green pod length and specific to the environment, 2020-MZM and 2020-BPN, while MZWB-L2 was found adapted explicitly for the 2021-MZM environment for green pod length. For 100 seed weight, RWBGP-97 is found to be specifically adapted for 2021-MZM while MZWB-L2 was identified as superior for green pod yield/plant and adapted explicitly to both 2021-MZM and 2020-BPN environments as genotype and environments belong to the same sector interact favourably. For seed yield/plant, MZWB-L2 was found to be specifically adapted for 2021-MZM environment.

The AMMI stability value (ASV) is the most appropriate tool for describing the stability of genotypes which can be calculated for each genotype by the relative contributions of the principal component axis scores (IPCA1 and IPCA2) to the interaction sum of squares followed as per Purchase *et al.* (2000). As per the ASV ranking (Table 5), the most stable genotypes were MZWB-L1, AKWB-1 and RMDWB-1 for green pod length as determined by the lowest ASV value. Among these, only MZWB-L1 has a higher green pod length above the grand mean. For 100 seed weights, the most stable genotypes were MZWB-L2, IWB-1 and MZWB-L1 across the environment. Out of these; only IWB-1 exhibited a mean 100 mean seed weight above the grand mean. In contrast, the most unstable genotypes were AKWB-1, RWB-39 and RMDWB-1. ASV ranking selected RMDWB-1, RWBGP-96 and RWB-37 as the most stable genotypes, although all these genotypes have lower green pod yield/plant than the overall mean. While MZWB-L1, RWBGP-96 and RWBGP-97 exhibited lower ASV values and were found more stable for seed yield/plant, all these genotypes except RWBGP-97 have higher mean seed yield/plant than the overall mean. Based on the stability score, RWB-39, IWB-1 and AKWB-1 were found to be the most unstable genotypes for seed yield/plant (Table 5). ASV is helpful in our study because it uses two IPC scores to provide a balanced measurement between them. In our investigation, the first two IPCs accounted for a significant component of GEI, which explains a major proportion of the overall variation. It is desirable to select genotypes with high yield and good environmental stability for variety recommendation as low yield with high stability is not desirable for mass cultivation. In contrast, high yield with low stability is desirable for a specific selection.

Table 5. AMMI stability value (ASV) of eleven genotypes on four important traits of winged bean.

Genotypes	Green pod length (cm)	100 seed weight (g)	Green pod yield/plant (kg)	Seed yield/plant (g)
AKWB-1	0.69	6.07	0.34	28.00
RMDWB-1	0.94	2.59	0.06	7.64
RWBGP-96	2.44	1.32	0.02	3.02
RWBGP-95	1.31	1.91	0.26	4.60
IWB-1	4.76	1.28	0.47	37.30
RWB-39	1.83	15.30	0.61	85.90
MZWB-L1	0.50	1.29	0.19	2.60
MZWB-L2	15.7	0.70	1.2	9.43
RWB-37	5.6	1.94	0.05	4.33
RWB-38	2.87	1.79	0.13	4.68
RWBGP-97	12.4	2.31	0.14	4.21

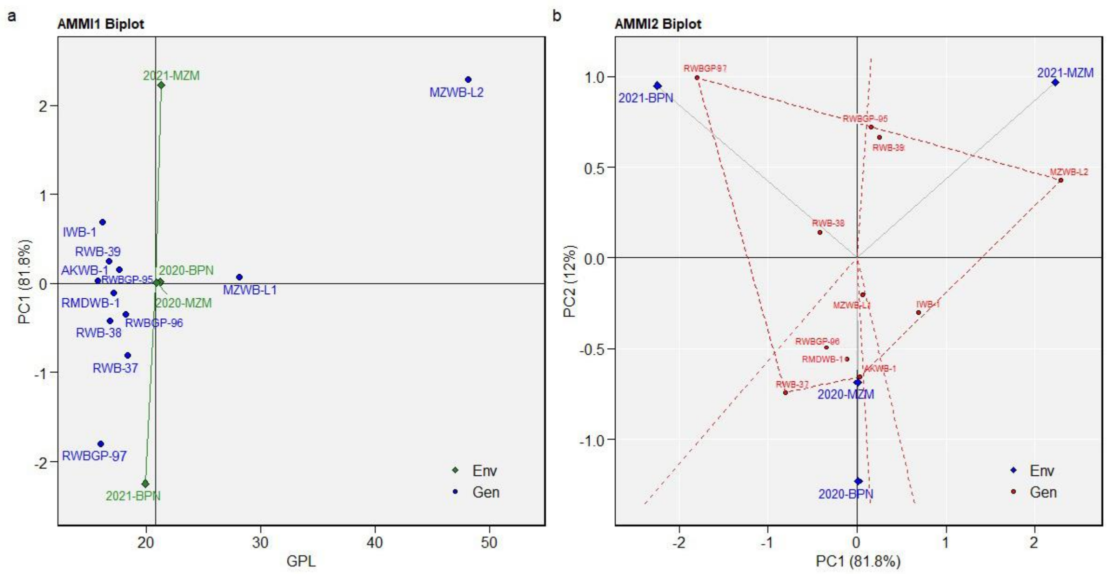

Figure 2. AMMI1 (a) and AMMI2 (b) biplots of 11 genotypes of winged bean for green pod length (cm) across four environments

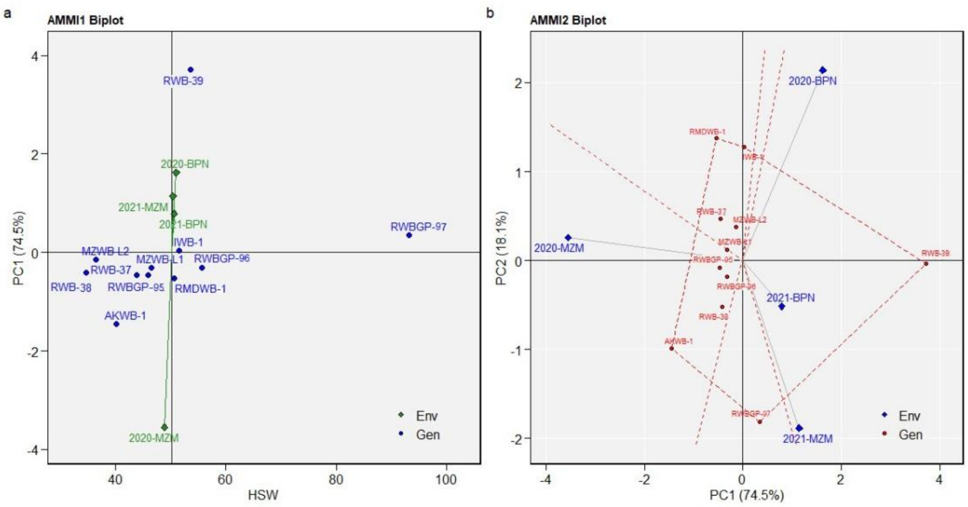

Figure 3. AMMI1 (a) and AMMI2 (b) biplots of 11 genotypes of winged bean for 100 seed weight (g) across four environments.

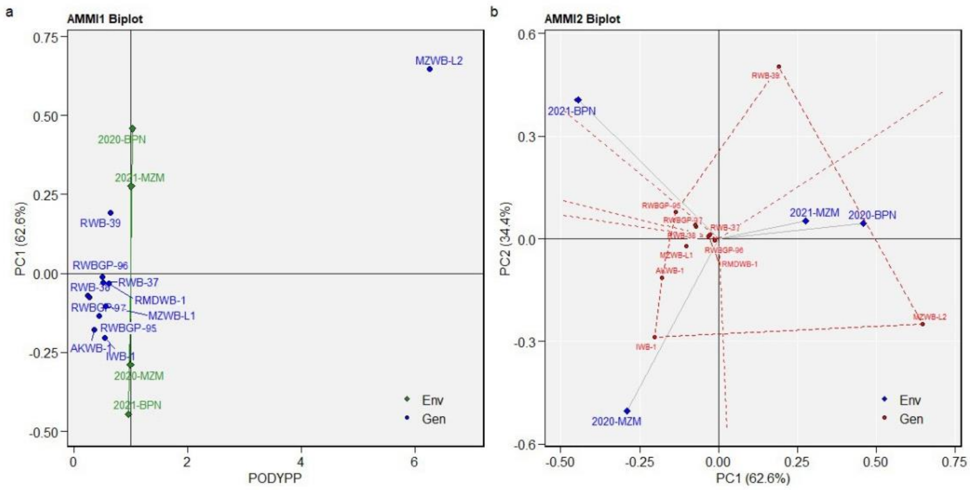

Figure 4. AMMI1 (a) and AMMI2 (b) biplots of 11 genotypes of winged bean for green pod yield/plant (kg) across four environments.

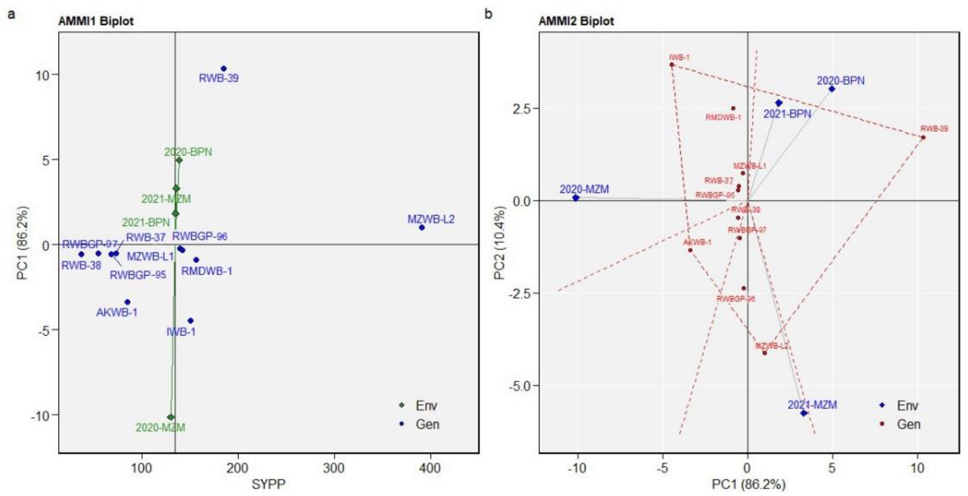

Figure 5. AMMI1 (a) and AMMI2 (b) biplots of 11 genotypes of winged bean for seed yield/plant (g) across four environments.

4. Conclusion

The studied genotypes vary in their leaf shape, leaflet size, pod surface, pod shape, seed colour and seed shape. Extensive collection of germplasm and characterization is necessary, which is facilitated by the vast diversity present in the region. Based on performance, the genotype 'MZWB-L2' exhibited significantly highest in yield and other yield component traits as compared to local and national checks with 47.97 cm green pod length (130.8% higher than its grand mean), 3.60 cm green pod width, 110.76 g green pod weight, 55.67 no. of pods/plant, 19.04 no. of seeds/pod, 6.25 kg green pod yield/plant and 391.20 g seed yield/plant. AMMI statistical model is a helpful tool that gives information on GEI. Results revealed that the winged bean yield and yield component traits were significantly influenced by GEI, genotypic and environmental effects. It aids in selecting superior and stable genotypes for both environment-specific and general adaptation. In this study, the genotype MZWB-L2 performed excellently well for all the yield and yield components than other genotypes in all the environments. However, it is found stable only for 100 seed weights across the environments tested. It has specific adaptations for green pod length (2021-MZM), green pod yield (2021-MZM & 2020-BPN) and seed yield/plant (2021-MZM) and is highly suitable for commercial cultivation in these regions. Moreover, this genotype is suitable for use as a potential parent in crop improvement programmes. The genotypes 'MZWB-L1' and 'RWBGP-96' were identified as the most stable genotypes that exhibited lower GEI and thus performed satisfactorily for all the yield and yield component traits across a wide range of environments. These genotypes are suitable for cultivation in the Northeast hilly region of India.

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